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(58) (71) (72) & (74) continued overleaf

(54) Electro-convulsive treatment apparatus

(57) An apparatus for electro-convulsive treatment has means for supplying pulses of current to output terminals P1, P2. An indicator M3 (Fig. 4) indicates the peak current passed during the treatment, the current being sensed at a resistor R1 also used to sense the peak voltage and charge supplied to the patient, voltage and charge being shown on further indicators M2, M4 (Fig. 4). A digital meter may indicate current and voltage and can be used ratiometrically to indicate patient resistance. A capacitor C2 is first charged and then discharged through the patient via a transistor T3 controlled by a circuit CC (Fig. 2) which gives a predetermined number of high current pulses followed by pulses of lower current. Pulse width rate and current amplitude are independently adjustable for both the high and low current pulses. Commutating transistors T4 to T7 controlled by circuit CM allow choice of various unipolar or biphasic pulse outputs, Figs. 3C to 3F. The charge supplied to the patient may be monitored during only the high current pulses (Fig. 5). Meter M1 across capacitor C2 may be calibrated in terms of charge, so that the charge in its reading indicates charge supplied. By monitoring the voltage on capacitor C2 or the signal to charge meter M4, supply of pulses may be stopped automatically when the patient has received a predetermined charge (Fig. 6). The output circuit may be modified to act as a constant current source for certain levels of patient resistance. Transistor T3 to T7 are controlled via opto-isolators I3 to I7.

Fig. 1.

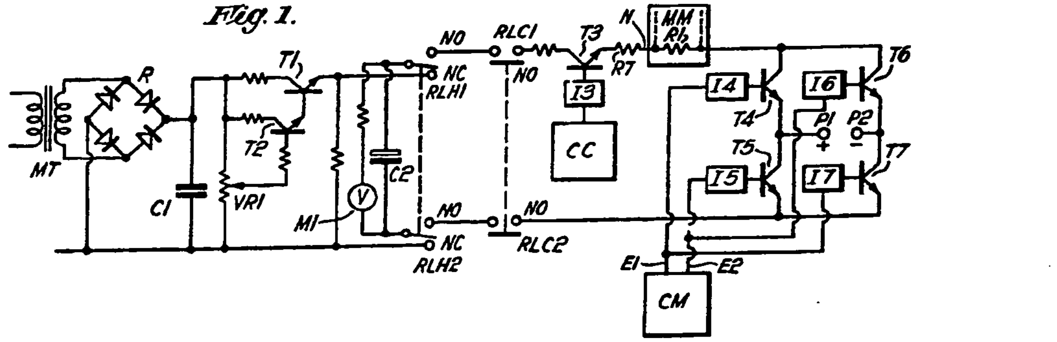
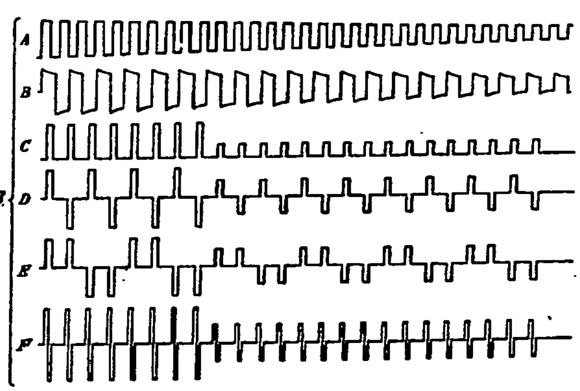


Fig.3.



The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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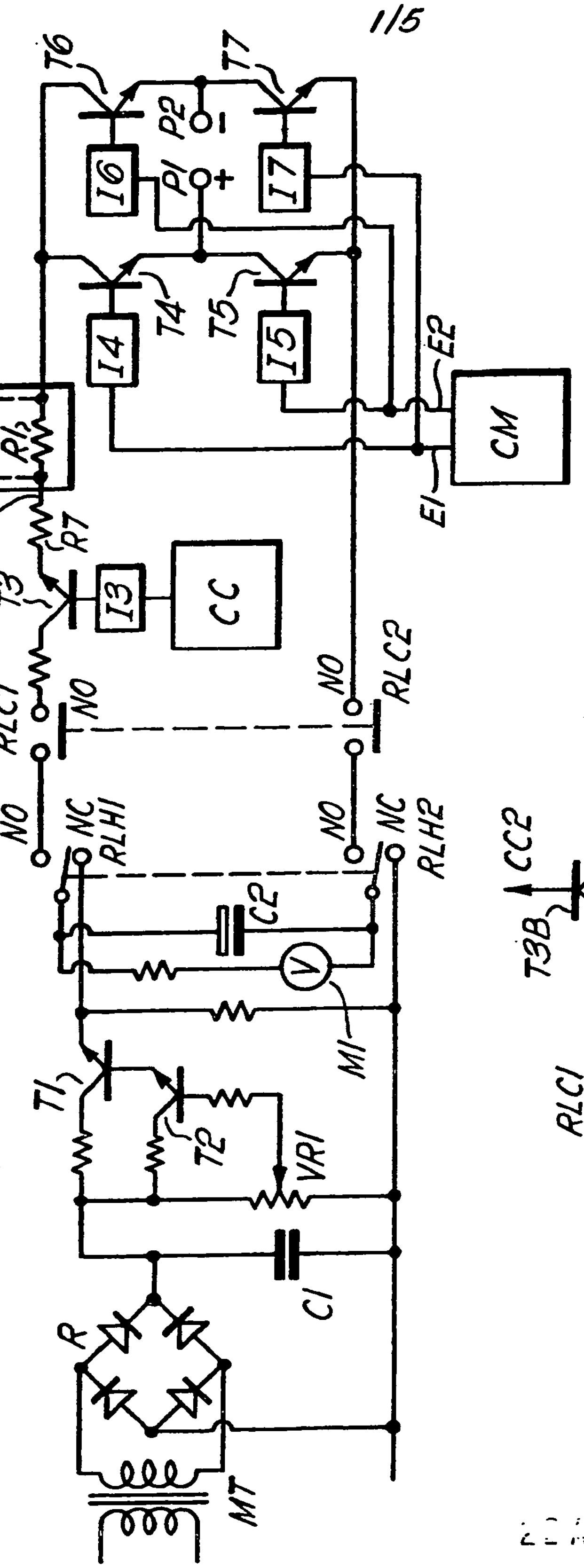

Fig. 1.

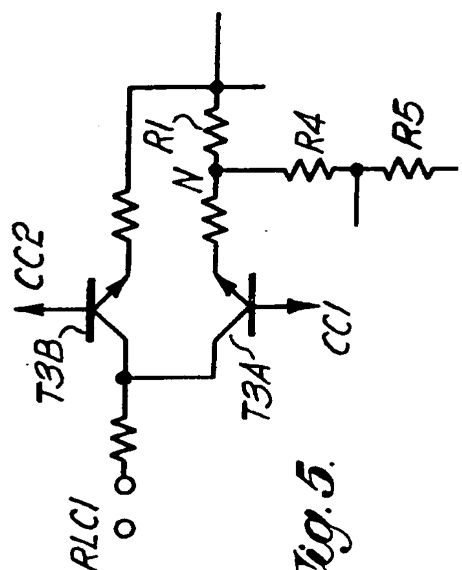

Fig. 5.

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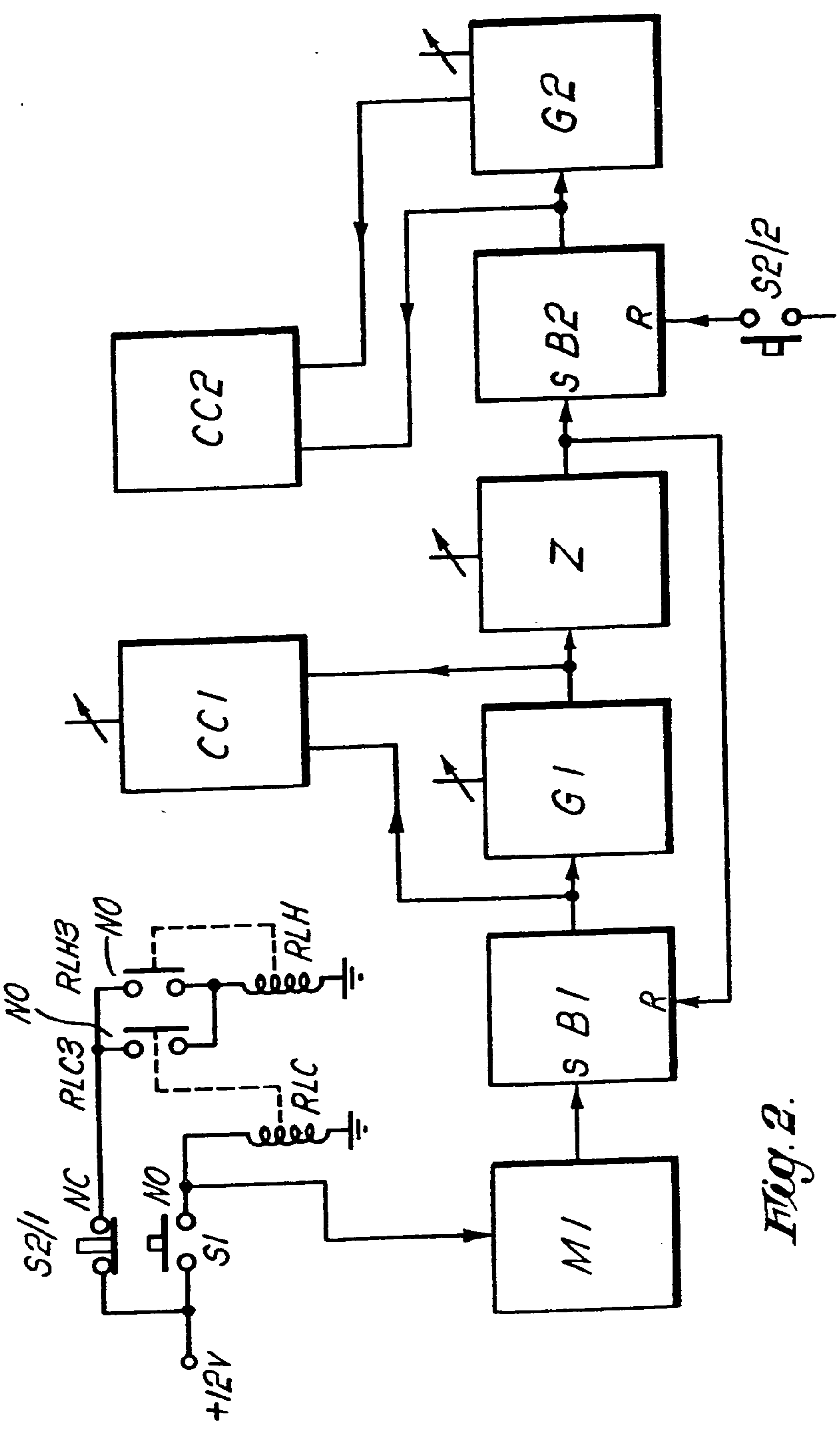


Fig. 2.

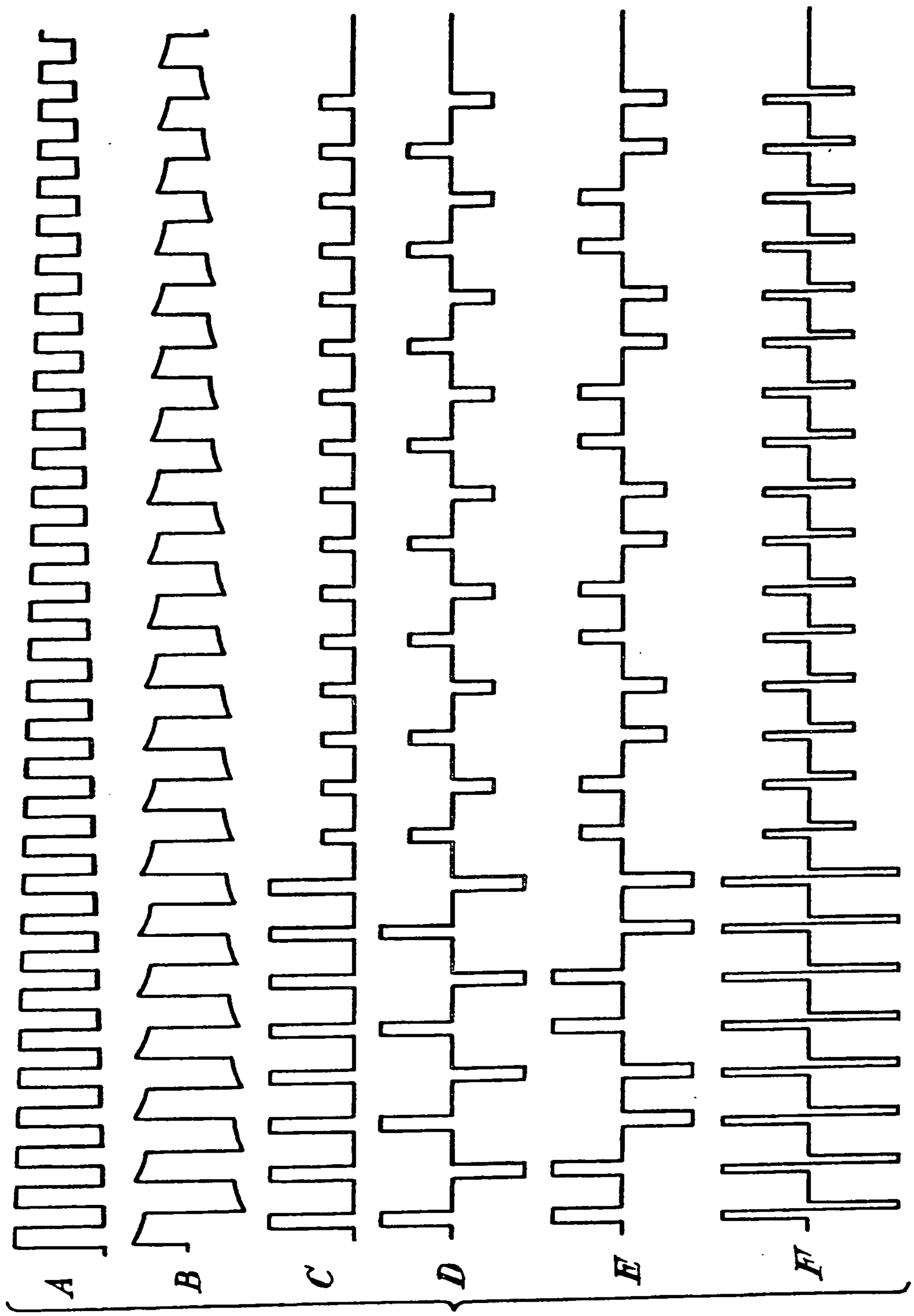


Fig.3.

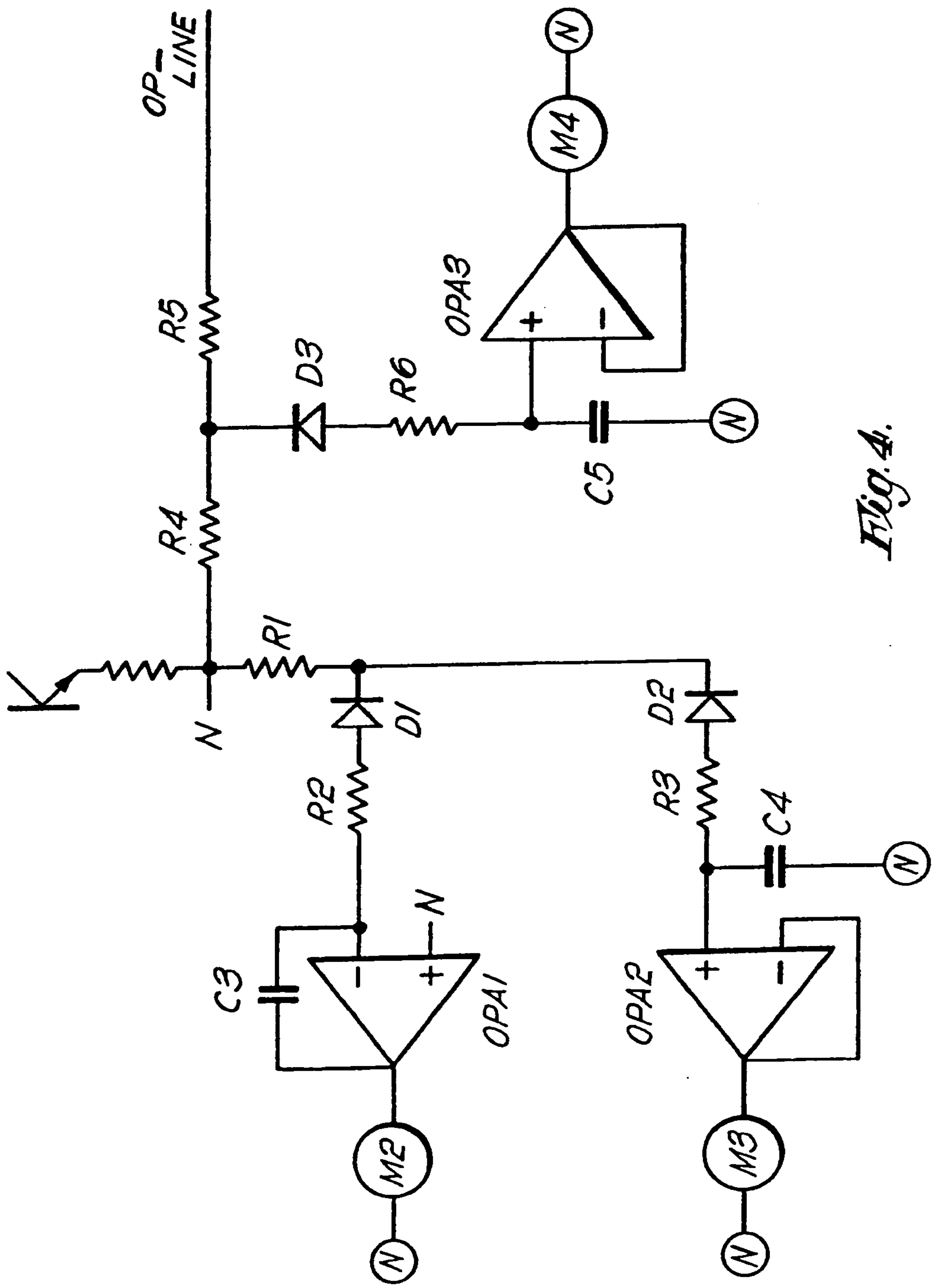
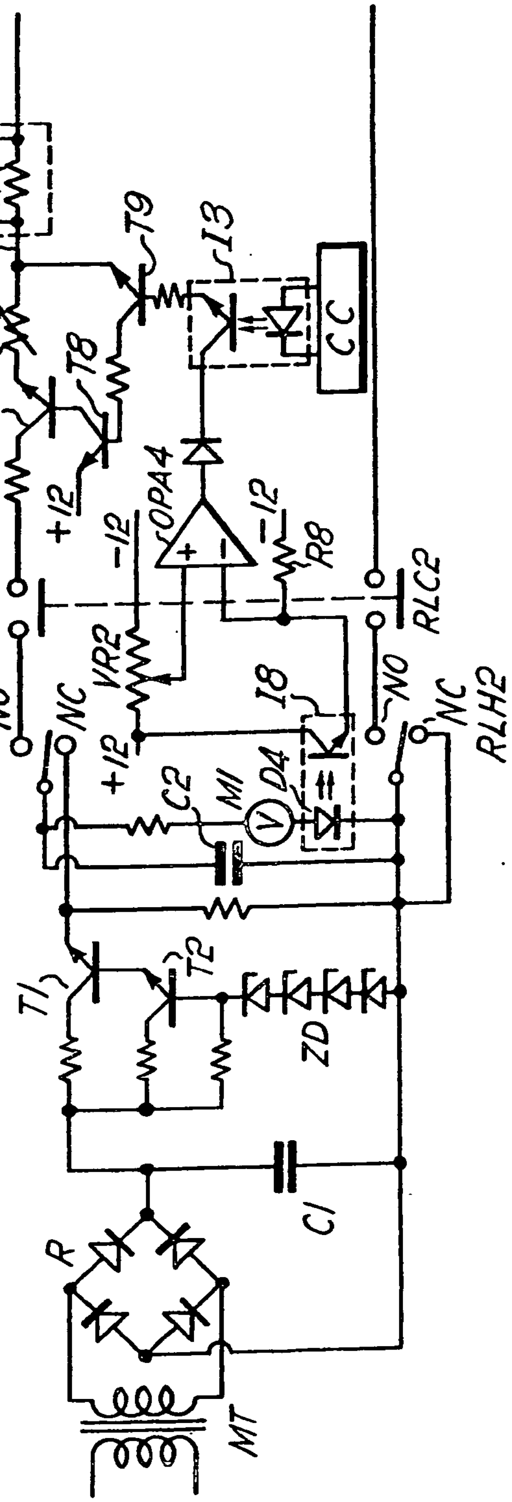

OP-
LINE
R5
D3
R6
OPA3
M4
N
C5
R4
R1
N
D1
D2
R2
R3
C4
C3
OPA1
OPA2
M2
M3

Fig.4.


MM
Rl
N
VR3
T9
I3
T3
T8
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+12
OPA4
-12
-12
R8
RLC1
RLC2
VR2
NO
NC
I8
RLH1
+12
C2
M1
D4
NO
NC
RLH2
T1
T2
ZD
C1
R
MT

Fig. 6.

SPECIFICATION

E.C.T. apparatus

This invention relates to apparatus for use in electro-convulsive treatment (E.C.T.).

This has been used for many years for the treatment of mental depression and involves passing an electric current through the brain of the patient via electrodes placed on the head. The treatment is usually given from one side of the head to the other in the region of the temples but the best modern technique is to pass the current through the "non-dominant" hemisphere from the forehead to the skin just behind the ear. In right-handed persons the left hemisphere is usually dominant. The term "convulsive" arises from the fact that the passage of the electricity stimulates the motor areas of the brain causing involuntary muscle movements: indeed it is found that if insufficient electricity is passed to produce a generalised convulsion there is no improvement in the depression. There is thus a tendency to err on the side of excessive current although a side effect of this treatment is impairment of memory, which is found to be more marked the greater the current passed.

There are two types of equipment generally used for this purpose. In the original type the current was obtained directly from a transformer operating at mains frequency (50–60 Hz), although in modified versions the current may be full-wave rectified or otherwise distorted, for example by a thyristor circuit which suppresses the first 40% of each half cycle, producing pulses of 6 ms duration at 10 ms intervals.

In the second type a large capacitor is charged to a high voltage (e.g. 500 V) and discharged through the patient via an interrupter to give approximately a square wave (e.g. at 100 Hz) with a 1:1 mark-space ratio and of diminishing amplitude, as shown in Fig. 3A. A series capacitor may be included in the output circuit to give symmetrical positive and negative pulses as shown in Fig. 3B.

Generally the current is passed for between one and five seconds, the capacitor losing most of its charge within the first half second. Despite the use, nowadays, of anaesthetics and relaxing drugs, the current causes an immediate tensing of the patient's muscles. This is followed by a period of progressive relaxation of the muscles: after about two to six seconds rhythmic muscle twitches are visible in the muscles of the patient's face, hands, neck or feet. If this rhythmic twitching does not occur, this indicates that there has been no generalised electrical discharge on the surface of the brain, the cortex, and a further treatment, with a larger dose is given.

The inventor has recognised the desirability of keeping the quantity of electricity passed through the brain low whilst still giving rise to convulsion, and that the quantity required varies with such factors as the patient's skull thickness; also the voltage necessary for a given current depends on the resistance of the patient, which can vary very considerably.

In one aspect, the invention provides an apparatus for electro-convulsive treatment comprising means for supplying pulses of current to output terminals connected to electrodes for applications to the patient, and indicator means arranged to indicate the maximum current passed to the output terminals.

Preferably the means for supplying pulses of current is arranged to supply pulses of short duration relative to their repetition period.

Although it is not intended that the invention be construed with reference to any particular theory, it is believed that sharp edged pulses provide a greater effect (at least until their rise time becomes comparable with the response time of the nervous system), whilst increase in the duration of the pulse beyond a certain point is a disadvantage.

In practice, pulses of 1 ms duration are found satisfactory: if the duration is shorter than about 0.8 ms their effect is reduced, whilst increasing the duration much above this level gives no improvement. A preferred range would be from 0.6 ms to 2 ms.

The rest period between current pulses is significant. It is well known in electro-physiology that the passage of current through part of a nerve will prevent an action potential from travelling along it. This inhibitory effect is reversible with time (provided the current is not such as to destroy the tissue). A recovery time is thus necessary, and supplying pulses too rapidly is wasteful. A repetition period of from 10 to 40 ms is found satisfactory.

In a further aspect the invention provides an apparatus for electro-convulsive treatment comprising means for supplying pulses of current to output terminals connected to electrodes for application to the patient and includes pulse control means arranged when actuated to cause supply of a predetermined number of pulses at a first current followed by further pulses at a lower current.

Thus, in use of the apparatus, the patient is initially given a number of high current pulses. The equipment then changes automatically to a much lower current amplitude which would preferably be controllable and would not have ceased when the patient reached the stage of showing evidence of a convulsion: the operator could then terminate the treatment but if the twitching ceased immediately he could restart under low current conditions. This may be contrasted with the known method in which all the current is passed well before the twitching stage is reached so that no further control is possible.

Preferably also the apparatus includes sec-

ond indicator means arranged to provide an indication dependent on the magnitude and duration of the current passed. The indicator means may be an integrator which measures the total output charge, indicated for example in millicoulombs, but it is not essential that a perfect integrator be employed.

It will be appreciated that by the provision of means for accurate measurement of the quantity of charge employed, the operator, upon the basis of his experience of the relationship between the charge required and other factors such as skull thickness (which can be determined by X-rays), can accurately assess and administer the required dose.

Conveniently, the first and second indicator means could employ a common series resistor for measuring the current supplied to the patient.

In a yet further aspect the invention provides an apparatus for electro-convulsive treatment comprising means for supplying pulses of current to output terminals connected to electrodes for application to the patient, and means for reversing the direction of current flow. This can be arranged for polarity reversal of alternate pulses, for a plurality of pulses in one direction followed by a plurality in the opposite direction; or for bipolar pulses.

This can suitably be achieved by the use of a commutating circuit comprising four transistors in a bridge circuit: in a preferred arrangement the transistors are switched by control signals supplied from a suitable generator via opto-isolators so that the patient circuit can be isolated, for safety, from the power supply. The current meter and charge meter (if any) should preferably be connected before the commutating arrangement so that it always operates with unidirectional current.

In another aspect the invention provides an apparatus for electro-convulsive treatment comprising means for supplying pulses of current to output terminals connected to electrodes for application to the patient, and charge control means responsive, in use, to the passage of a predetermined quantity of electrical charge to the terminals, to automatically terminate the supply of said pulses.

Exemplary embodiments of the invention will now be described with reference to the accompanying drawings, in which:—

Figure 1 is a schematic diagram of one embodiment of E.C.T. apparatus according to the invention;

Figure 2 is a block diagram of the control circuitry of the apparatus of Fig. 1;

Figures 3A and B illustrate output waveforms obtained with certain types of known apparatus;

Figures 3C, D, E and F illustrate waveforms obtainable using the apparatus of Fig. 1;

Figure 4 is a circuit diagram of the charge, maximum current and maximum voltage meters of the apparatus of Fig. 1; and

Figure 5 illustrates a variant of the output switching arrangement of Fig. 1.

Figure 6 is a diagram similar to Fig. 1, showing a further embodiment.

The apparatus shown in Fig. 1 comprising a d.c. power supply in which a double-wound mains transformer MT feeds a smoothing capacitor C1 via a bridge rectifier R. The d.c. voltage which may, for example, be of the order of 350 V, is variable by means of a potentiometer VR1, transistors T1, T2 and associated resistors. This voltage is supplied via changeover contacts RLH1, RLH2 of a hold relay RLH to a reservoir capacitor C2, typically 800 μF. Passage of charge from the capacitor to the output switching circuit is controlled by a pair of normally open contacts RLC1, RLC2 of a further relay RLC (control relay), and the capacitor voltage is measured by a voltmeter M1. The voltmeter may be calibrated in volts, but more conveniently may be calibrated in charge (e.g. 0–300 mc) and/or energy (e.g. 0–50 J). An analogue meter is preferred in this position so that poor electrode contact is readily manifested as an unsteadiness of the meter needle.

The output switching circuit comprises a switching transistor T3, the base of which is controlled by a current control circuit CC which feeds, via a commutating arrangement comprising four transistors T4–T7 connected in a bridge circuit, a pair of output terminals P1, P2 for connection to the patient. A resistor R1 is connected in series with the emitter of the transistor T3 and forms part of a peak current meter and, optionally, charge meter circuit, described below. A series resistor R7 is also included to limit the initial current surge. Control signals are supplied to the base electrodes of the transistors T4–T7 via opto-isolators I4–I7 from a commutating control circuit CM.

The control circuitry of the apparatus is shown in Fig. 2. The details of this are most conveniently explained with reference to the operation of the apparatus.

Initially the two relays RLC, RLH are de-energised, so that the contacts RLH1, RLH2 are in the position shown and the contacts RLC1, RLC2 are open (Fig. 1). The reservoir capacitor C2 is charged by the power supply to a voltage determined by the setting of the potentiometer VR1.

The apparatus is operated by depressing a pushbutton switch S1. This energises the coil of the control relay RLC, closing the contacts RLC1, RLC2 so that the output switching circuit is connected to changeover contacts RLH1, RLH2 of the hold relay RLH. Auxiliary contacts RLC3, connected in series with the hold relay RLH close, energising this relay which switches the changeover contacts RLH1, RLH2, isolating the reservoir capacitor C1 from the power supply and connecting it to the output circuit via the contacts RLC1,

RLC2. The hold relay has auxiliary contacts connected in parallel with the contacts RLC3, so that this relay latches until it is de-energised by opening the contacts S2/1 of a reset switch.

In addition to operating the relays, operation of the switch S1 also supplies a signal, via a monostable circuit MS1 which introduces a delay sufficient to allow completion of the relay operation, to set a first bistable circuit B1. When set, the bistable B1 starts a pulse generator G1 and permits the switching transistor T3 to be operated by a high current control circuit CC1 to pass current pulses to the output terminals P1, P2. The control circuit CC1 has means (not shown) for adjusting the magnitude of the current, and includes a monostable circuit for varying the duration of the pulses whilst the frequency of the pulses is determined by the pulse generator G1 which also has means for varying the frequency. The pulses produced by the pulse generator are also fed to a presettable counter Z. When the counter has counted a predetermined number of pulses it produces an output signal which resets the bistable B1, disabling the current control circuit CC1 and pulse generator G1, thereby terminating this "high current" phase of operation. At the same time, this signal from the counter sets a second bistable circuit B2.

This bistable B2 controls a low current control circuit CC2 and a pulse generator G2 which operate in the same way as the high current control circuit CC1 and pulse generator G1 except that the current passed to the output terminals is lower. Again, the current and the pulse duration and frequency is adjustable. Obviously a single pulse generator may be used if the repetition rate of the high and low current pulses is always to be the same. The production of low current pulses continues indefinitely as long as the operating button S1 remains depressed.

When S1 is released, the control relay RLC is de-energised, so that its contacts RLC1, RLC2 open and current flow ceases. However, the hold relay RLH remains held, so that the reservoir capacitor C2 is not recharged: also the state of the bistables B1, B2 is unaffected, so that low current operation can be resumed simply by closing the contacts of S1 once again.

Resetting of the apparatus to its initial state is effected by operating the reset switch which releases the hold relay (contacts S2/1) and resets the bistable B2 (contacts S2/2).

A typical current output waveform (unidirectional current) is shown in Fig. 3C, where eight high current pulses are followed by pulses of lower current.

The commutating transistors T4–T7 are provided to effect polarity reversal of the output current. Current at the terminals P1, P2 of the polarity shown (P1 = +, P2 = −) can be obtained with control signal E1 which, via the opto-isolators I4, I7, turns on transistors T4 and T7, whilst the reverse polarity can be obtained by switching on transistors T5 and T6 via the opto-isolators I5, I6 with a control signal E2.

The signals E1, E2 are produced by the commutator control circuit CM which can be set for unidirectional current of either polarity but also contains circuitry controlled by the pulse generators G1, G2 whereby a diphase output can be obtained. For example the signals E1, E2 may be obtained from a bistable circuit clocked by the generator pulses, so that the output pulses alternate in polarity, as indicated in Fig. 3D, or from a divide-by-n circuit, where groups of n/2 pulses alternate, as shown in Fig. 3E (n = 4). Alternatively, the polarity may be switched during a pulse, as illustrated in Fig. 3F, for example by employing a monostable circuit having a period equal to half the pulse duration arranged to trigger the commutation circuit.

The charge, peak current and peak voltage meter arrangements will now be described with reference to Fig. 4 . When current flows to the output, a small voltage drop occurs across the series resistor R1 (Fig. 1) which may typically have a value in the range of 1Ω to 10Ω. The volt drop is always of the same polarity, irrespective of the output polarity, as the current at this point is always in the same direction.

This voltage is fed via a diode D1 and a series resistor R2 to an integrator comprising a differential amplifier (conveniently an FET operational amplifier) and a capacitor C3. The diode prevents discharge of the integrator being caused by leakage currents in the commutating and output circuits. The other input of the differential amplifier is connected to the neutral point N. A voltmeter M2 is connected to the output of the integrator. Power supplies of + 12 volts and − 12 volts for the amplifier are obtained from an isolated supply whose 0 volts terminal is connected to the neutral point N of the meter circuit.

In operation, successive voltage pulses formed across the resistor R1 progressively charge the integrator capacitor C3, so that the capacitor voltage and hence the reading on the meter M2, increase providing an indication of the charge (millicoulombs) which has been supplied to the patient. The circuit, when correctly biased, is close to being a true integrator, although if the operating conditions are altered it can be arranged that pulses below a certain amplitude are ineffective and those above it are reduced in amplitude by that amount. If appropriately adjusted, the integrator may disregard the low-current pulses completely, which may be desirable in some circumstances, since as far as possible damage to the patient is concerned it may be of more value to know the sum of the high-

current pulses than of all pulses irrespective of amplitude. Alternatively, if it is desired to measure only the charge output during the high-current pulses, this can be achieved by using separate switching transistors T3A, T3B for high- and low-current switching, and inserting the charge meter in series with only one, as illustrated in Fig. 5.

It may also be noted that if, as suggested above, the voltmeter V1 is calibrated directly in terms of charge, the charge delivered may be measured by noting the change in the reading of V1, so that it is possible to omit the separate charge meter.

Fig. 4 also shows the peak current and peak voltage meters. The voltage pulses developed across R1 are fed via a diode D2 and a series resistor R3 to a capacitor C4, which consequently charges up to the peak value of the largest pulse. Similarly, the output voltage across the patient circuit is fed via a potential divider comprising R4 and R5 (typically $R5 = 99 \times R4$), via a diode D3 and series resistor R6 to a capacitor C5 which charges up to a voltage proportional to the peak output voltage. The capacitor voltages (and hence the peak current/voltage) are monitored via further FET operational amplifiers OPA2, OPA3 this time connected as straightforward non-inverting amplifiers, by voltmeters M3, M4 respectively. Although three meters are shown in the arrangement of Fig. 4, obviously a single meter could be used for the two functions, via suitable switching means. In addition, by using a digital meter ratiometrically the resistance of the patient circuit can be indicated directly. Also the analogue arrangements shown could be replaced by an analogue-to-digital converter and a memory for each quantity, whereby errors in readout due to diode non-linearity and drift due to leakage currents can be reduced.

In a further variant of the apparatus, a trigger circuit is included so that when the charge passed to the patient reaches a selected figure the current is switched off automatically, thus terminating the treatment. Although this could be linked to a charge meter of Fig. 4, in the preferred arrangement (Fig. 6) the voltage on the reservoir capacitor C2 is used as the criterion for switch-off. The diode D4 of an opto-isolator I8 is connected in series with the voltmeter M1, whilst the associated transistor, with the emitter load resistor R8, is connected to non-inverting input of a differential amplifier OPA4 whose inverting input is connected to a potentiometer VR2 which provides an adjustable threshold voltage.

In use, when a predetermined quantity of charge has passed to the patient, the voltage on capacitor C2, and hence the current through the opto-isolator I8 and voltage across R8, drops below the threshold voltage set by VR2, whereupon the amplifier OPA4 cuts off the supply to the opto-isolator I3 and hence disables the control transistor T3. It will be appreciated that this arrangement presupposes a known initial charge on the capacitor C2, and therefore the potentiometer VR1 is replaced by a fixed voltage reference, such as a chain of zener diodes ZD. Fig. 6 also shows a further (optional) modification in which the current feedback resistor R7 is replaced by a variable resistor VR3, and current control transistors T8, T9 whereby the transistor T3 (when enabled) acts as a constant-current source — although the extent to which the current set by VR3 will be achieved will be dependent on the patient's resistance.

CLAIMS

1. An apparatus for electro-convulsive treatment comprising means for supplying pulses of current to output terminals connected to electrode for applications to the patient, and indicator means arranged to indicate the peak current passed to the output terminals.

2. An apparatus according to claim 1, in which the means for supplying pulses of current is arranged to supply pulses of short duration relative to their repetition period.

3. An apparatus according to claim 2 in which the pulses have a duration of from 0.6 ms to 2 ms.

4. An apparatus according to claims 2 or 3 in which the repetition period of the pulses is from 10 ms to 40 ms.

5. An apparatus according to any one of the preceding claims in which the means for supplying pulses of current includes pulse control means arranged when actuated to cause supply of a predetermined number of pulses at a first current followed by further pulses at a lower current.

6. An apparatus according to any one of the preceding claims including second indicator means arranged to provide an indication dependent on the magnitude and duration of the current passed.

8. An apparatus according to any one of the preceding claims including charge control means responsive, in use, to the passage of a predetermined quantity of electrical charge to the terminals, to automatically terminate the supply of said pulses.

9. An apparatus for electro-convulsive treatment comprising means for supplying pulses of current to output terminals connected to electrodes for application to the patient, and charge control means responsive, in use, to the passage of a predetermined quantity of electrical charge to the terminals, to automatically terminate the supply of said pulses.

10. An apparatus according to claim 9 in which the means for supplying pulses of current includes a capacitor which can be charged to a predetermined voltage and dis-

charged via the output terminals, and the charge control means comprises a comparator arranged to terminate the supply of pulses when the voltage on the capacitor falls below a threshold value.

11. An apparatus for electro-convulsive treatment substantially as hereinbefore described with reference to the accompanying drawings.

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